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Evaluation of Passive RFID System in a Dynamic Work Environment

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Overview

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Motivation

- Lots of prospective avenues for improving safety and quality of patient care. Developing a context aware system in a trauma room will aid teamwork and improve the efficiency.

- Radio Frequency Identification (RFID) has been one of the most widely used sensing technologies.

- RFID technology can be used to be a part of the context aware system in the trauma room.

- The deployment of the RFID system in a trauma room requires a good study about the trauma room requirements and the end goal of the application which in our case is activity recognition.

- Developing a system deployment strategy to aid the RFID setup deployment in a dynamic work environment will improve the performance of the system.

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Contribution of the thesis

- Evaluation methodology for the Passive RFID System in a dynamic work environment.
- Highlights the RFID system performance in challenging environment.
- Lists the requirements and challenges faced in a trauma bay.
- Performance of different RFID setups – read rates, distribution distance and classification accuracy.
- Discussed the tag placement requirements and strategies – read rates.
- Insights into features and classifiers that could be used for state identification.

RFID Technology

- Definition – Radio Frequency Identification is the use of an radio frequency tag incorporated on an object for identification purpose.

- A typical RFID system comprises of :
  1. RFID Reader (a)
  2. Antenna (b)
  3. RFID Tag (c)

(a)

(b)

(c)

- Types of RFID Technology:

1. Active RFID Technology
2. Passive RFID Technology
3. Semi Passive RFID Technology

Passive RFID Technology – Advantages and Challenges

Advantages :

- No line of sight requirement
- Tags are cheaper and easy to deploy on objects
- Tags are re-programmable and no permanent data recorded
- Unlike computer vision, privacy is not invaded
- Enables faster and easier detection of multiple tags
- Less human intervention required

Challenges :

- Sensitive to environmental conditions
- Tags are affected by the characteristics of the object
- Limited read range

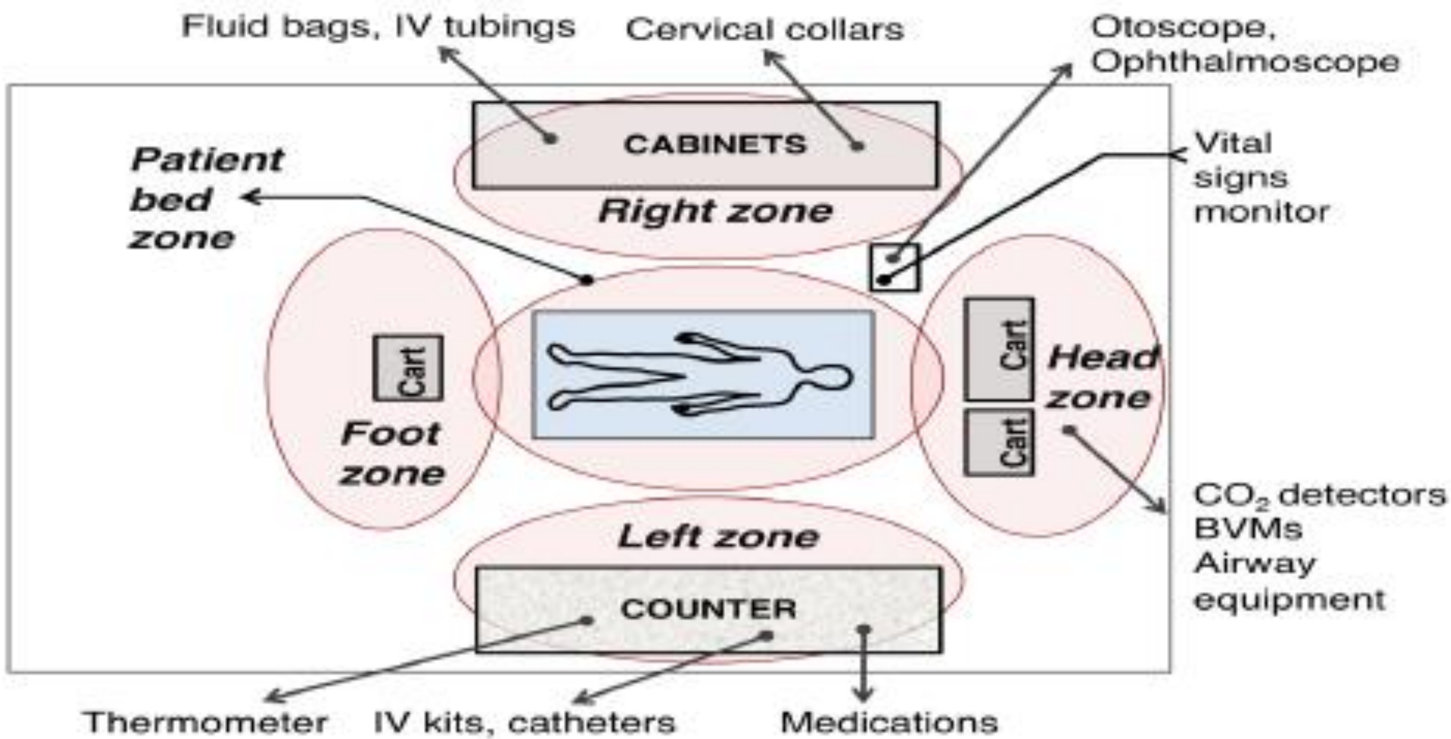
Evaluation of RFID System – Why do we need it ?

- No specific protocol present for RFID system design for sensing applications.
- Most of the previous research on this subject focuses on read rates which is not a good indicator for usage detection/activity recognition.
- Current practice is to place the antennas in a regular grid without any controlled experiments.
- Optimum placement problem is more difficult for RFID because of its sensing technology.
- RFID sensing system consists of two components :

  1) sensors on objects (RFID tags)

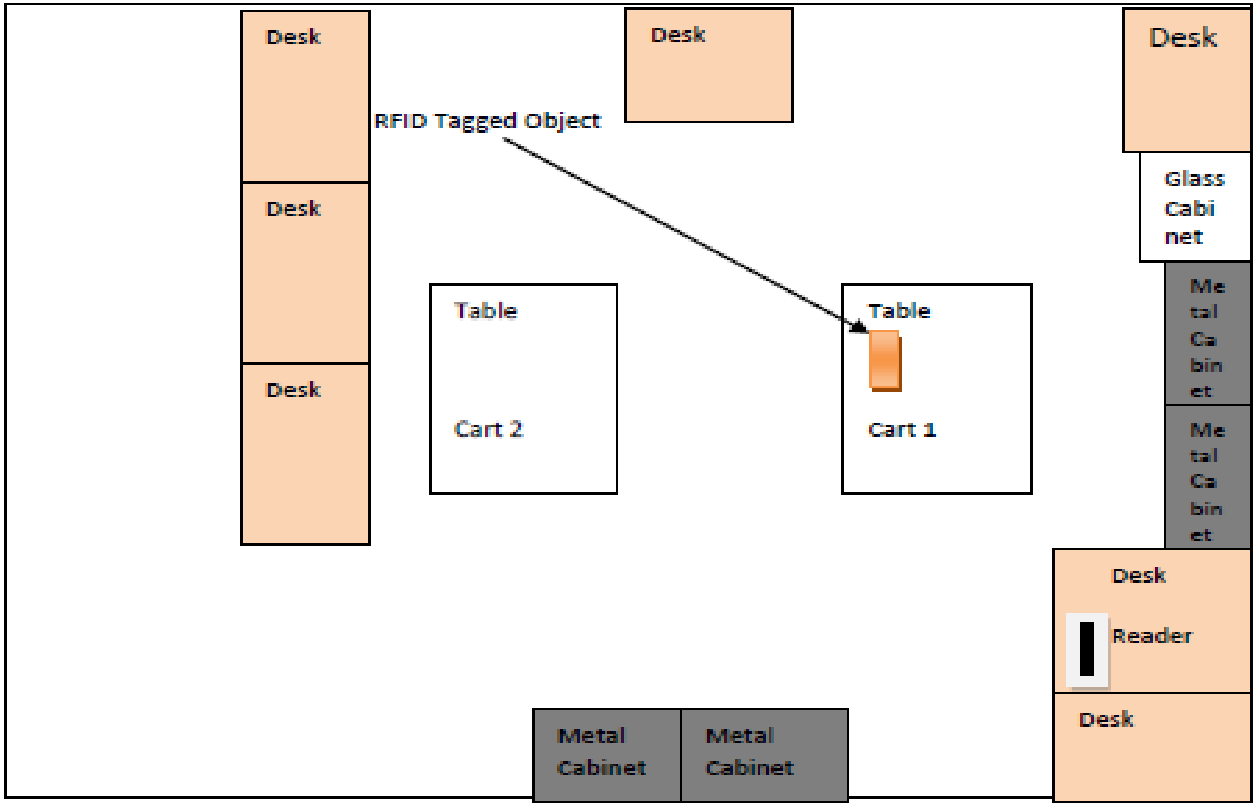
  2) readers (base stations)
- RFID system deployment strategy should take care of both these components separately.

Typical Trauma Bay Setup



- During trauma resuscitation, medical objects appear either on the patient bed zone or in one of the storage places (left, right, head and foot zones).
- Our prototype environmental setting in the lab includes only two zones: patient bed zone and one storage zone.

Experimental Lab Setup (Top View)



- Each zone contained a 0.9 m tall cart.
- The carts were separated between 0.8-2.3 m away from each other, depending on the experimental scenario.
- A cardboard rectangular box was tagged with an RFID tag and handled by the experimenter as the target object.

Antenna placement - Requirements

Antenna placement – Positioning of antenna in the system so as to transmit and receive the signals.

- Each zone should be covered by at least one antenna
- Object orientation should have minimal affects on signal reception
- Minimal effects due to environmental conditions on the system performance.
- Antenna positions should not affect the underlying task performance or hinder free movements
- Cost effective

Antenna Placement – Evaluation Criteria

1) Read Rates

- Number of responses obtained from a tag per unit time.
- Simple to calculate and provides basic information about the goodness of a setup
- Used widely in readability and coverage area related research

2) Use Detection Accuracy

- Represents the similarity between the hypothesis about object use and the ground truth
- Accuracy = (true positives + true negatives) / (total no. of test samples)
- Calculation of accuracy requires a recognition system, feature extraction, model training and classification steps.
- Measures setup goodness with respect to the sensing application of the system.

Antenna Placement – Evaluation Criteria (cont'd)

3) Distribution Distance

- Measures the difference between two distributions of signals.
- Used to calculate the difference between the RSSI patterns
- RSSI signal pattern is more fluctuating when the object is in use compared to when not in use.
- Distribution distance measures the goodness of a setup with respect to its sensitivity to changes in the object's state.
- A highly sensitive RFID setup is preferred since it will detect the change in the state of the object efficiently.
- Mahalanobis Distance is one such distribution distance metric that is used in our work.
- Mahalanobis distance is a measure of similarity between a vector and a set of vectors characterizing a distribution.

Antenna Placement – Evaluation Criteria (cont'd)

3) Mahalanobis Distance (cont'd)

- Mahalanobis distance of a multivariate vector *p* to a multivariate distribution *Q* with mean *μ* and covariance *S* is given by:

$$d_M(p, Q) = \sqrt{(p-\mu)^T S^{-1} (p-\mu)}$$

- We calculate the distribution distance between two RSSI patterns P and Q as:

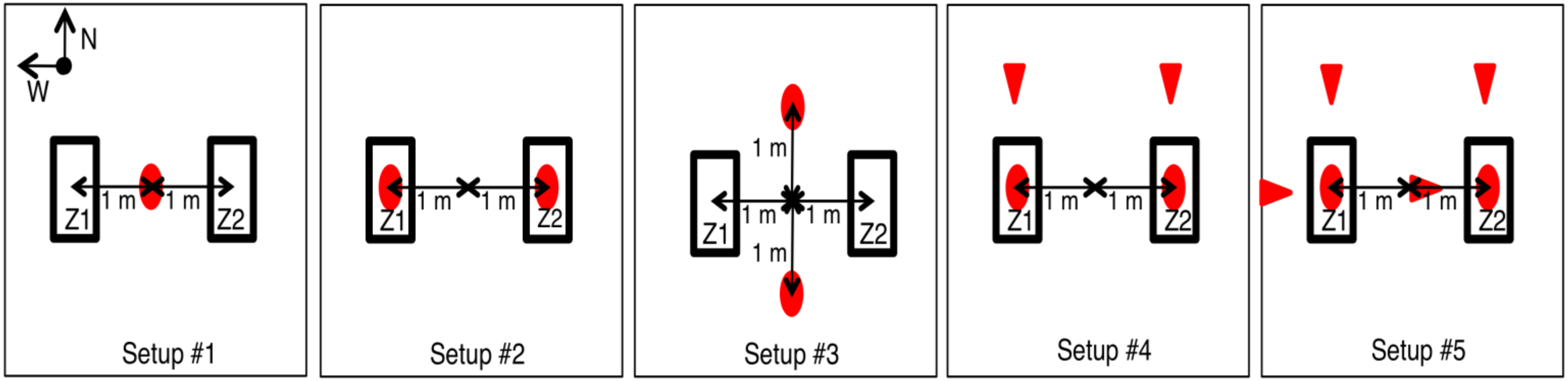
$$M(P,Q) = 1/2\,(m(P,Q) + m(Q,P)) - 1/2\,(m(P,P) + m(Q,Q))$$

where $m(P, Q)$ is defined as the average distance of samples in P to samples in Q:

$$m(P,Q) = \frac{1}{n} \sum_{i=1}^{n} d_m(p_i, Q)$$

Antenna Placement – Antenna Setups

Based on the study of a typical trauma bay, we have proposed five antenna setups:



- Setup 1 – one overhead antenna covering both zones
- Setup 2 – two overhead antennae directly above each zone
- Setup 3 – two overhead antenna perpendicular to line joining the centers of the two zones
- Setup 4 – one overhead antenna and one side antenna for each zone
- Setup 5 – one overhead antenna and two side antennae per zone

Antenna Placement – Experimental Scenarios

1) **Stationary environment** – baseline scenario, no environmental factors introduced (1)

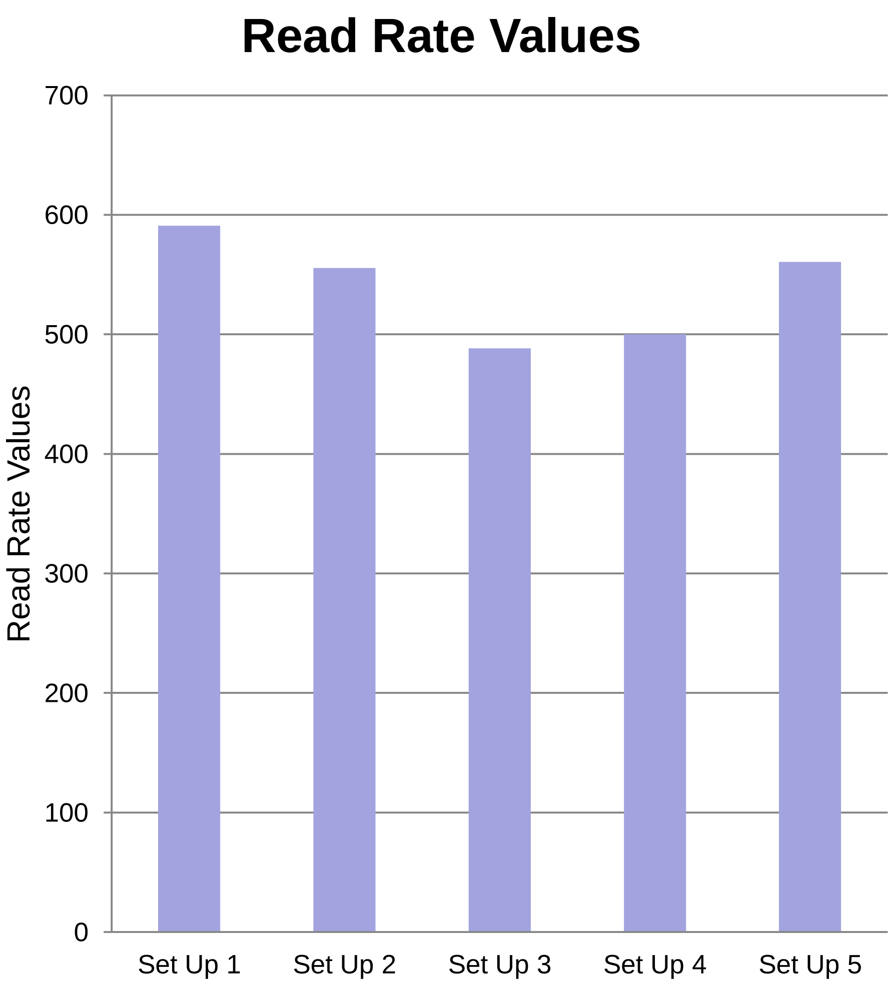
2) **Deviations in zone locations:**
   - Z1 and Z2 moved 0.6m to north (2-a)
   - Z1 moved 0.6m to north; Z2 moved 0.6m to south (2-b)
   - Z1 moved 0.6m to east; Z2 moved 0.6m to west (2-c)

3) **Changes in object orientation**
   - Tag faced north (3-a)
   - Tag faced west (3-b)

4) **Human Interference**
   - Two people walked around the zones (4-a)
   - Five people walked around the zones (4-b)

Antenna Placement – Location Change Results

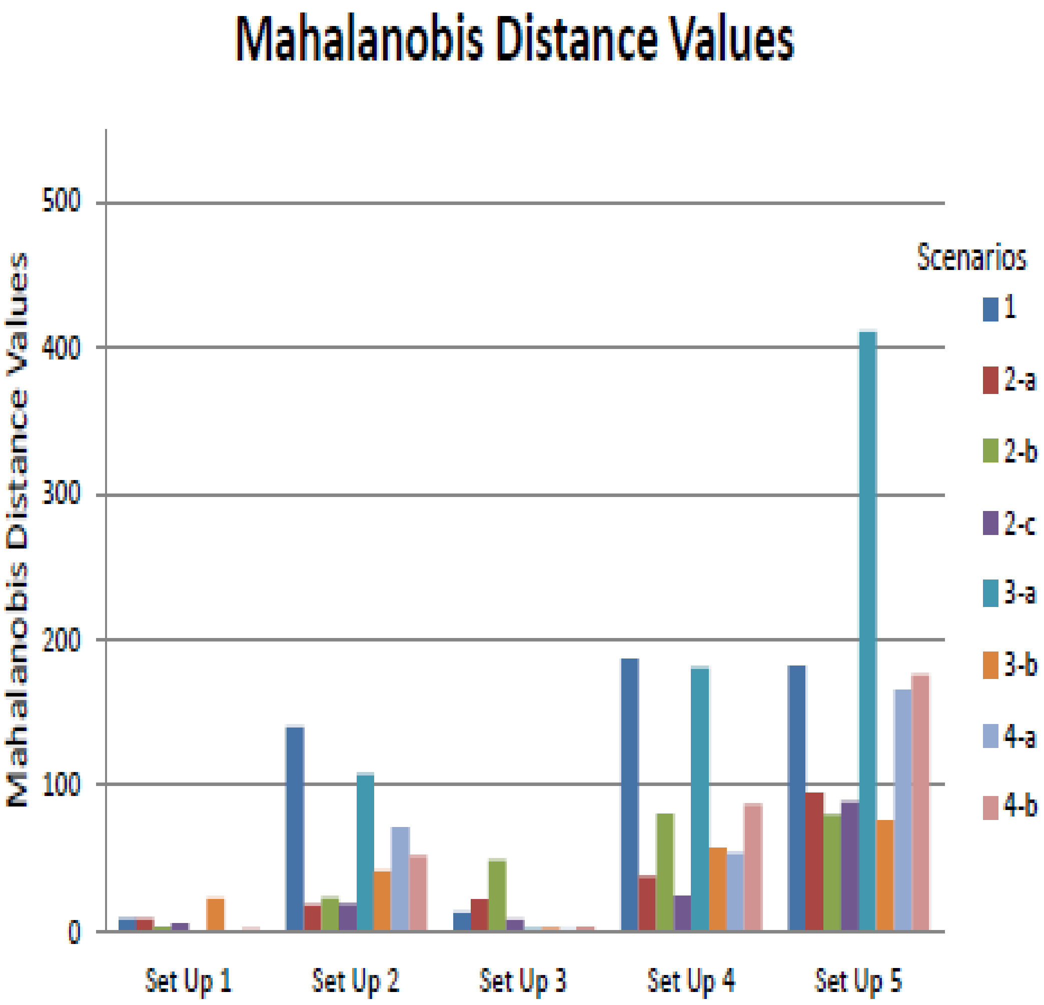
(a) Read Rate



- Setup 1 gave average read rates of ~ 30 reads/sec.
- Reader spends some time in switching between antennas for other setups.
- Setup 2 and Setup 5 read rates are very close following setup 1.
- Setup 5 shows consistency over different scenarios, thus showing its robustness to environmental changes.

Antenna Placement – Location Change Results (cont’d)

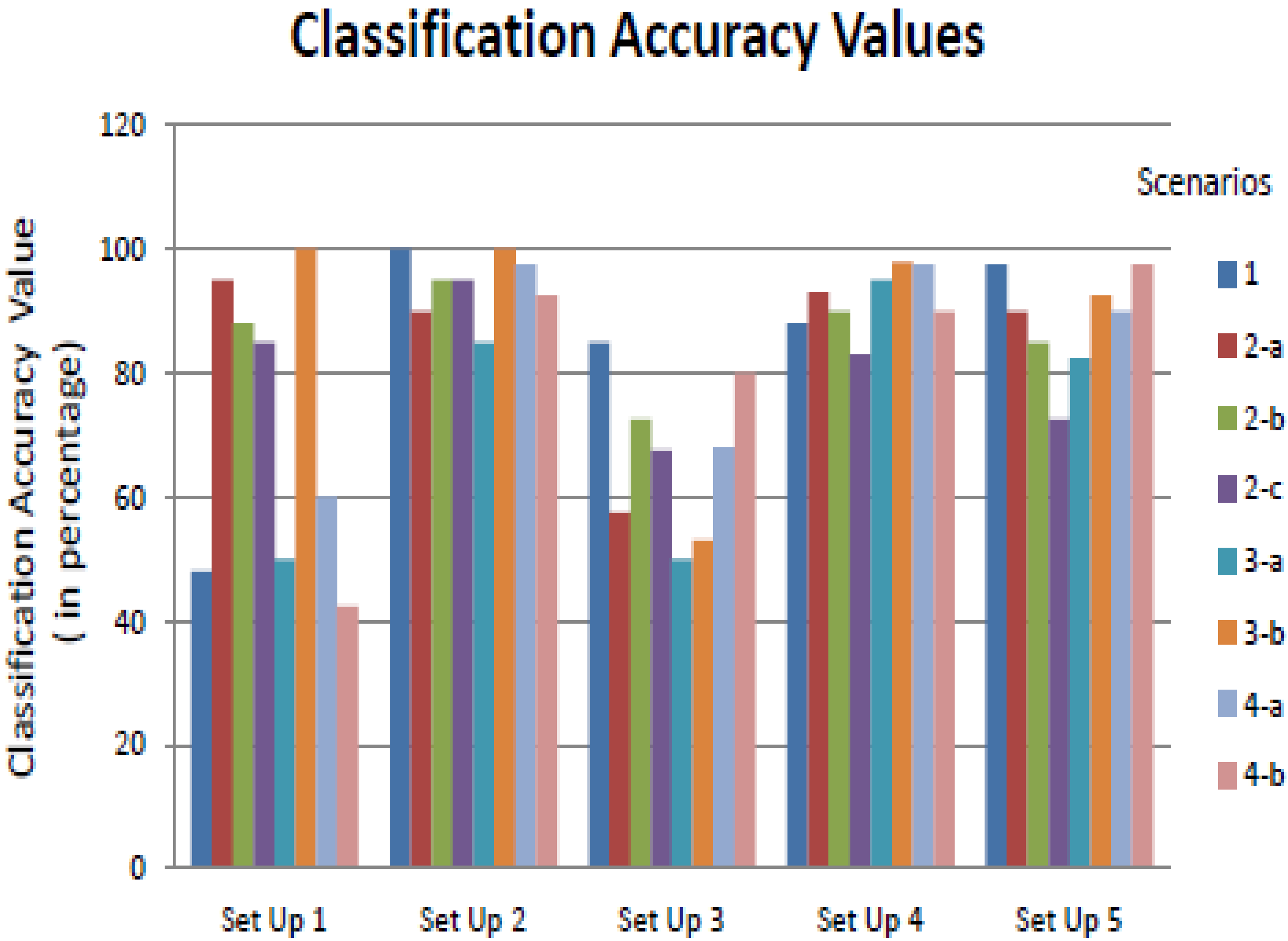
(b) Mahalanobis Distance



- Increasing pattern with increasing number of antennas.
- Setup 2 performed better than setup 3 in spite of same number of antennae.
- Setup 5 performed best among all the antennae.
- The high values of setup 2, 4 and 5 show the importance of a ceiling mounted antenna directly above each zone.

Antenna Placement – Location Change Results (cont'd)

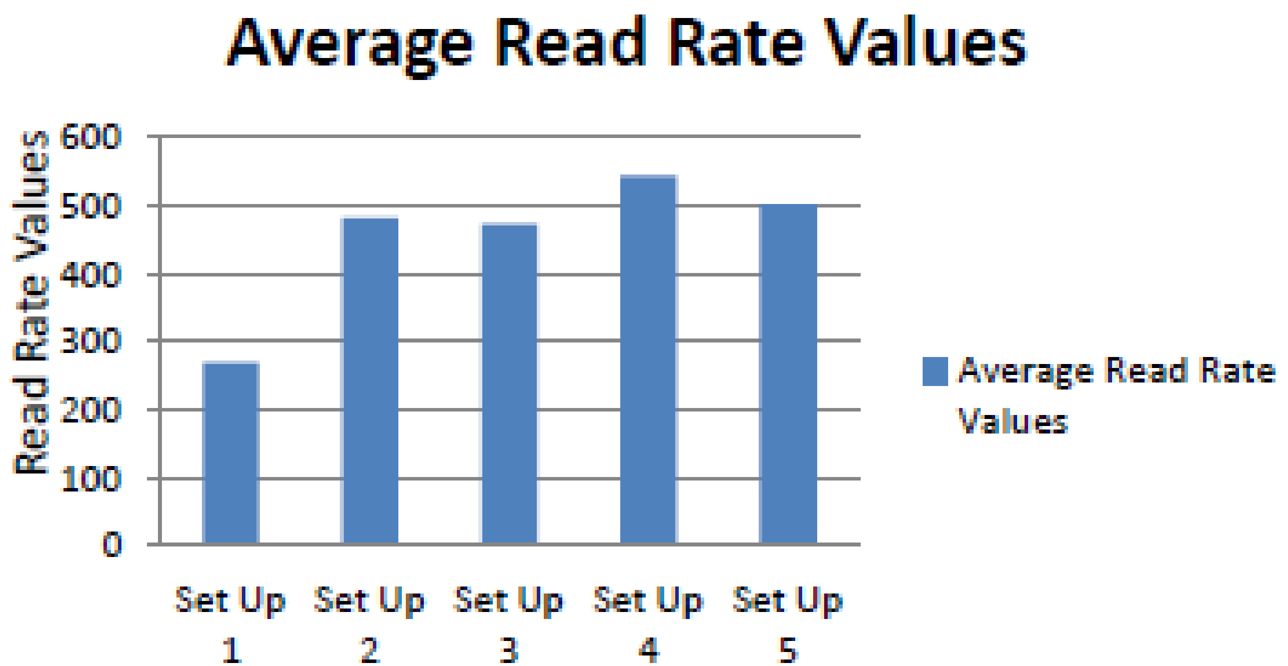
(c) Classification Accuracy



- Setup 2, 4 and 5 gave best zone based localization scores for all scenarios.
- Setup 2 and setup 5 have very close accuracy values signifying the importance and the impact of the overhead antenna.
- The side antennas however help the sensitivity of the system.
- Setup 3 performed the worst for location change detection implying the effect of a symmetric antenna setup.

Antenna Placement – Mobility detection Results

(a) Read Rates



- Read Rate values are very close for all the setups except setup 1.
- Setup 1 has only one antenna and is not susceptible to orientation changes during the mobility / usage of the object.
- Setup 2, 4 and 5 have slightly higher read rates for all the scenarios because of the presence of the overhead antenna over the patient zone.

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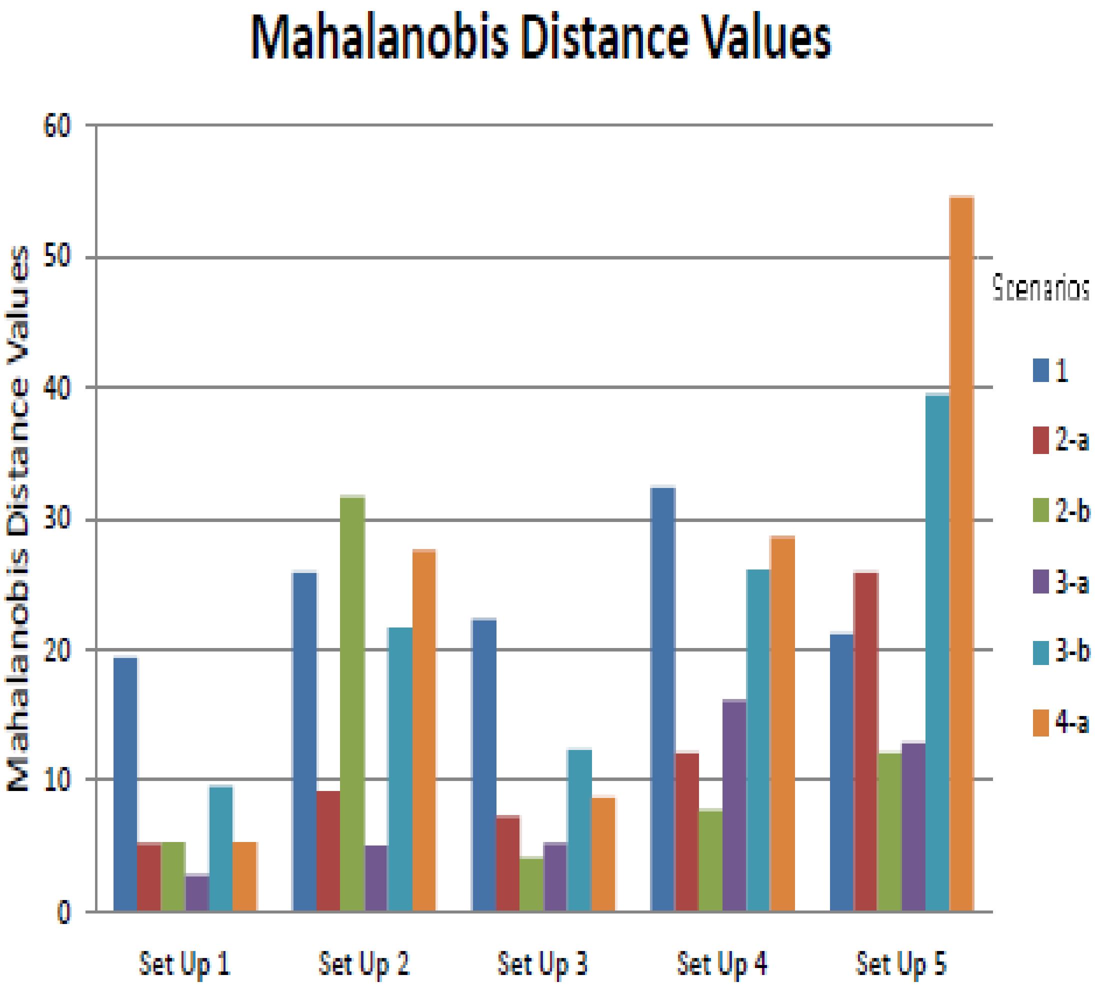
Antenna Placement – Mobility detection Results (cont'd)

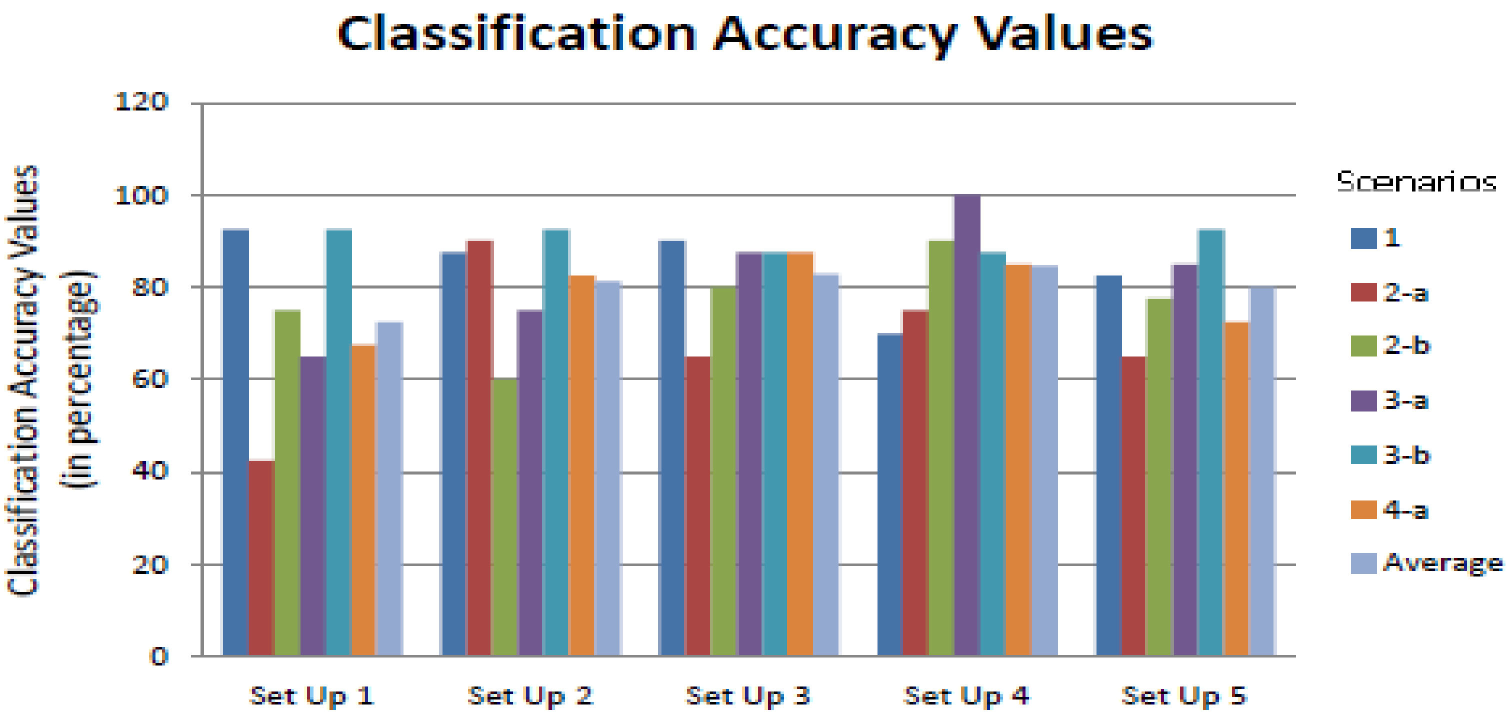
(b) Mahalanobis Distance



- Setup 2 and setup 4 have close second highest values whereas setup 5 outperforms the other setup.
- Setup 5 shows high sensitivity in the presence of human occlusion which is a notable thing.
- Mahalanobis distance values are in general lower than that for location change experiments.
- Usage of the object happens at the patient bed, hence resulting is lesser variations in the RSSI patterns.

Antenna Placement – Mobility detection Results (cont'd)

(c) Classification Accuracy



- Lesser RSSI variations result in low standard deviation, hence low classification accuracy.
- Setups 2,3,4 and 5 have very close average classification accuracy values.
- Setup 5 performed better for scenarios 1, 3-a,b which represent comprise of all the tag orientations.

Antenna Placement Experiments - Findings

- Including an overhead antenna increases the read rate, mahalanobis distance and the classification accuracy.
- Connecting multiple antennas to the same reader slightly reduces the read rates because of antenna switching.
- Multple antennae perform better because they are more robust to tag orientation changes.
- Setup 3 performed poor for location change experiments signifying the effects of a symmetric setup.
- The mahalanobis distance calculated is a multi dimensional metric and increases with increasing the number of antennas.
- The distribution distance is a direct measure of the sensitivity of the system to object changes and setup 5 is highly sensitive.
- Setup 5 performed better for location change experiment scenarios involving human movement. It also performed better for mobility experiments involving tag orientation changes.
- Setup 2 performs well with two antennae because of having two overhead antennae

Tag Placement – Introduction

Requirements

- Tag on each object
- Maximize the visibility to the antennae considering the possible orientations of that object.
- Metallic or liquid objects should have least contact with the tag, or special tags should be use.
- Tag shape should be preserved so that its antenna is not affected.
- Tag placement should hinder the underlying object's usage.
- Optimum number of tags should be placed on an object based on cost and tag collision.

Evaluation Criteria

Read Rates

- Read rates are highly sensitive to the tag placement.
- Material, shape, size of the object all play a role in tag placement.

Experimental Setup

- Setup 2 – one overhead antenna per zone
- Setup 5 – one overhead and two slanted antennae per zone
- Hybrid setup –The storage zone(Z1) had one overhead antenna (setup 2) and the patient bed zone (Z1) had one overhead and two slanted antennae (setup 5).
- The object was moved from the storage zone to the patient bed during the experiment.

Tag Placement – Experimental Scenarios

1. Tag placement depending on material of the object :
   - Studied the different placement types on liquid pouch to see the effect on read rates.

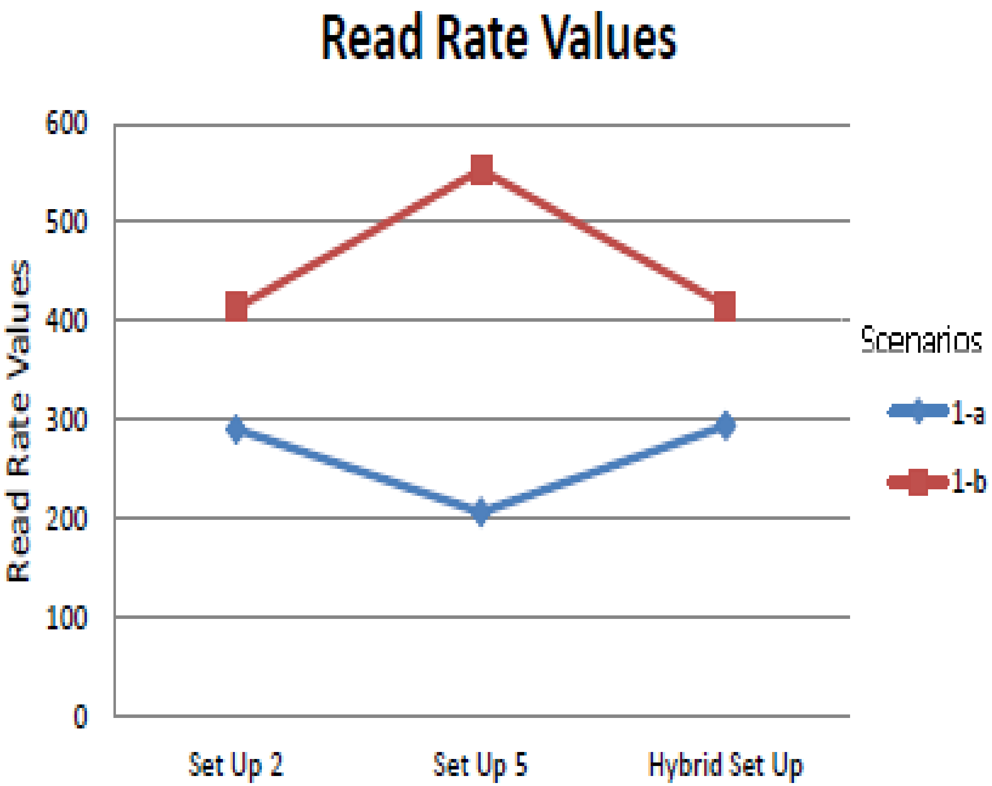
1. Determining the number of tags to be placed on an object :
   - Multiple tagging helps in reliable detection by minimizing the effects of a poor tag performance due to tag bending etc.
   - Experimented with Foley Catheter and Stethoscope
   - Multiple tagging also helps put usage detection in perspective while tagging an object.

2. Tag placement based on object shape
   - Study the effects of tag bending on read rates
   - Study the effects of placement of tag across different dimensions (width, length) on read rates.

3. Tandem tagging
   - Exploit contact cue for usage detection and study the effects on read rates
   - Experimented with objects having longer duration of use

Tag Placement – Results

<u>(1) Material (Liquid Container)</u>

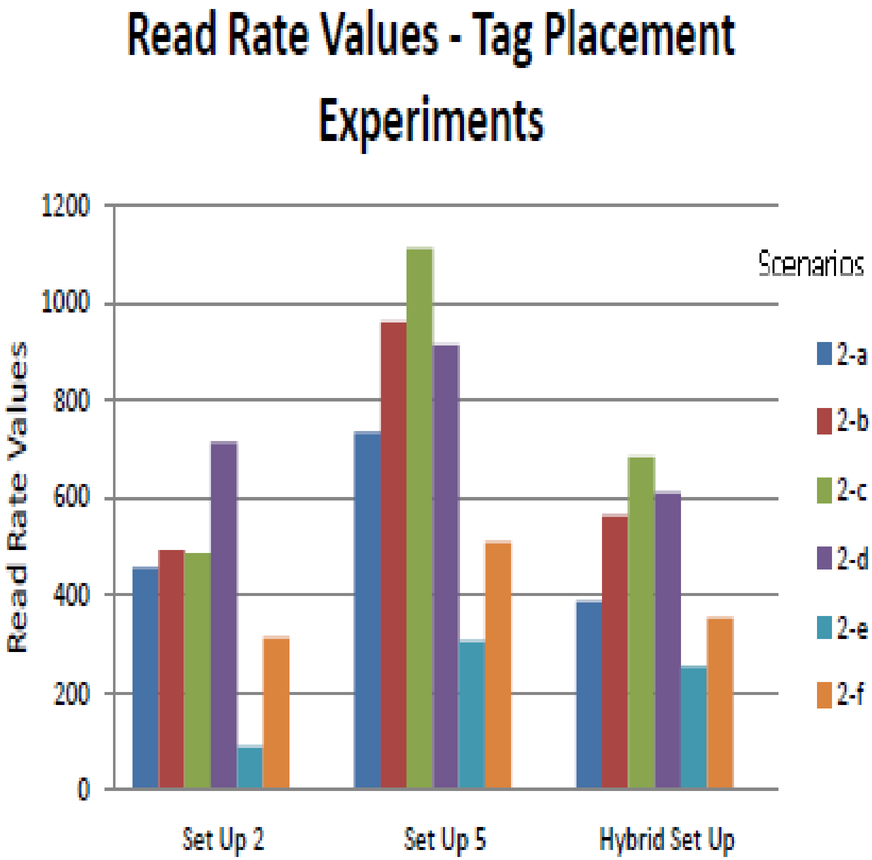


Scenario Number	Description
1- a	Tag attached along long edge
1- b	Tag attached along short edge

Less contact with the liquid container resulted in higher read rates as expected.

Tag Placement – Results (cont'd)

(2) Determining the number of tags

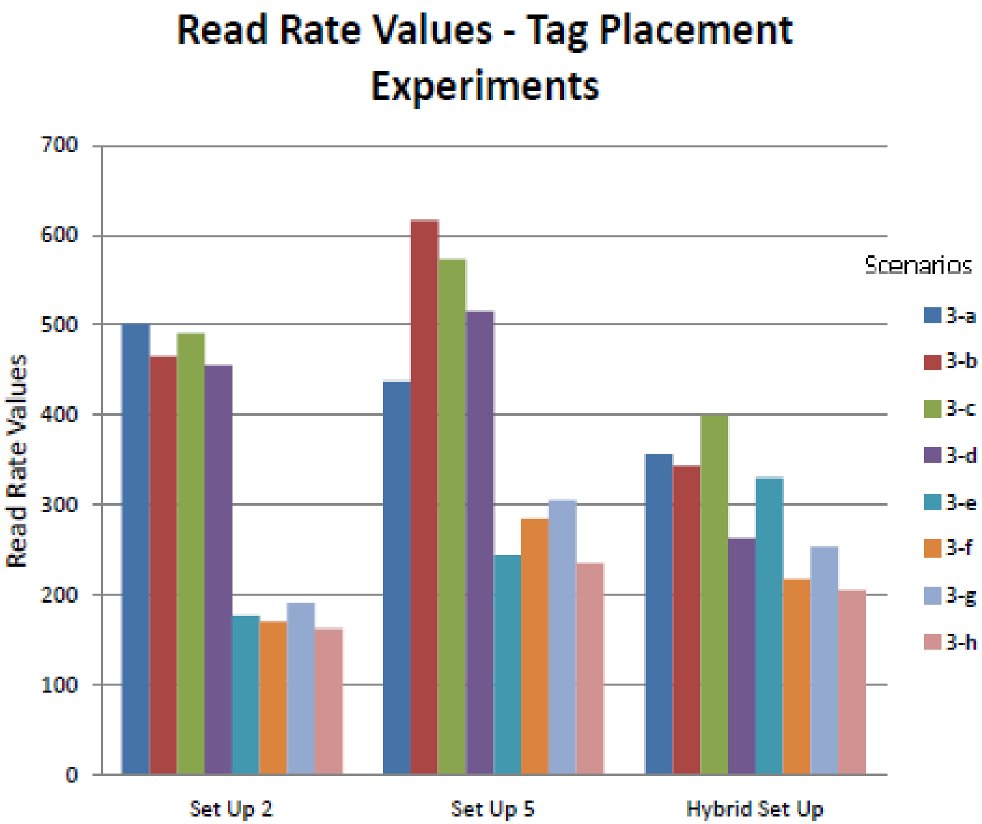


Scenario Number	Description
2- a	FC – 1 tag
2- b	FC- 2 tags, 6 inch separation
2- c	FC – 3 tags, 3 inch separation
2- d	FC – 2 tags, 2 inch separation
2- e	Stethoscope – 1 tag
2- f	Stethoscope – 2 tags

- Increasing the number of tags increased the read rates.
- The read rates from the foley catheter tags were close with the distances of 2 and 6 inch.

Tag Placement – Results (cont'd)

(3) Shape of the object (Tag Folding)



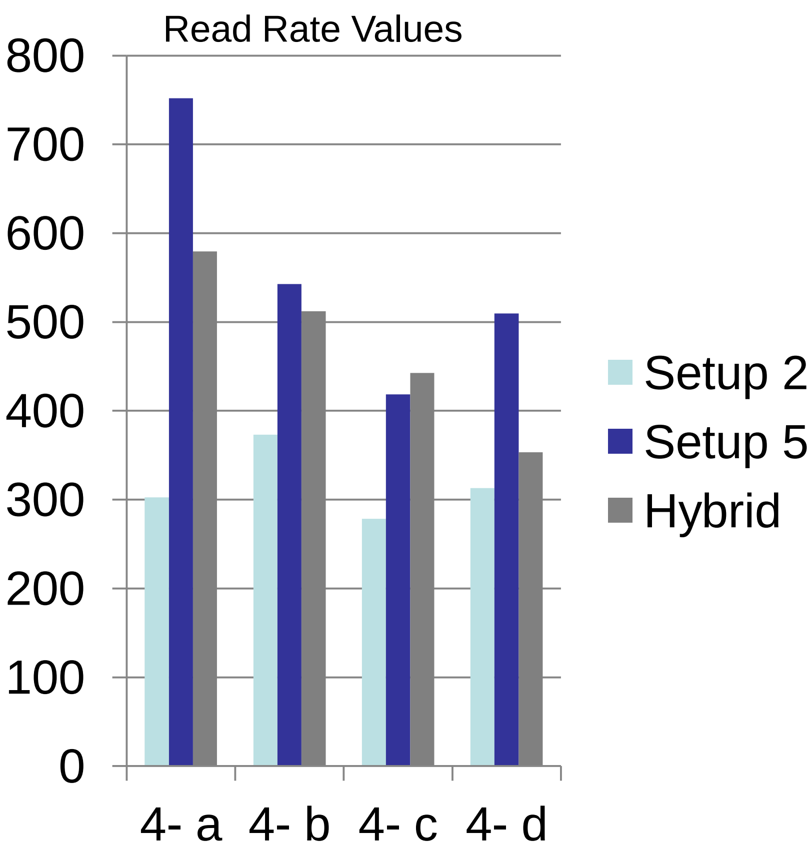
Scenario Number	Object Location	Description
3 – a	Cart	No Bending
3 – b	Cart	Little Bending – short edge
3 – c	Cart	Complete Bending – short edge
3 – d	Cart	Complete Bending – Long Edge
3 – e	Neck	No Bending
3 – f	Neck	Little Bending – short edge
3 – g	Neck	Complete Bending – short edge
3 - h	Neck	Complete Bending – Long Edge

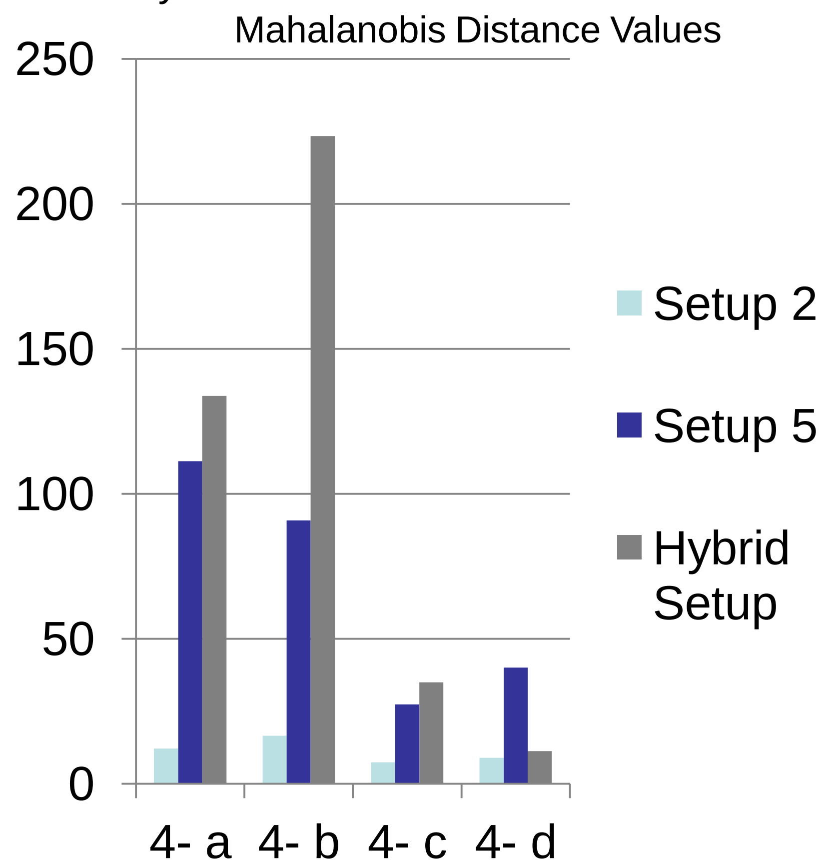
- In the presence of a slanted antenna, bending of tag increased the read rates. Tag bending however, decreased the read rates from the overhead antenna.
- Read rates are much lower when the stethoscope was around the neck of the user.
- Complete bending across the short edge performed better overall.

Tag Placement – Results (cont'd)

(4) Tandem Tagging

When the object is in use, the overhead antenna is not able to read the tag which is in contact with the user, while the slanted antennae detect it minimally.





4 –a : Collar both tags exposed,
4 –b : Collar one tag covered
4 –c : Stethoscope both tags covered
4 –d : Stethoscope one tag covered

Tag Placement Results (cont'd)

(4) Tandem Tagging (cont'd)

- Read rates as well as the mahalanobis distance increased with the proposed strategy for setup 2, because of the only overhead antenna.

- For setup 5, as the read rates decreased (for collar), the distribution distance also decreased. With stethoscope, as the read rate increased, the distribution distance also increased.

- For the hybrid setup, the read rate values and the distribution distance values were close.

- Setup 5 performed poorly in term of distribution distance with the proposed strategy mainly because more number of antennas were affected. Hence the multi-dimension distribution distance calculation used Gaussian distribution values.

Tag Placement - Findings

- While tagging liquid containers, minimum contact should be maintained with the object. Tagging along the width would serve this purpose.
- Multiple tags could be placed on larger objects with a tag separation of 2 inches. This would help in increasing overall the read rates.
- Tag bending affects the read rates from the overhead antenna. Setup 5 is a preferred setup when tag bending is done.
- Complete bending of the tag along the short edge is the preferred placement strategy for objects wired objects like stethoscope.
- Setup 5 performs better in terms of read rate when the object is in a hold state e.g. stethoscope is hung around the neck.
- Placement of a tag at the contact location of the object can act as a cue for usage detection.
- The tag placement problem was studied considering the domain of trauma bay. The problem in general is a very extensive field of study.

Classification Method – A Brief

1. Data Collection

Location Change Dataset = 200 recordings, 20s long each

Motion Detection Dataset = 150 recordings, 20s long each

2. Classification Algorithm

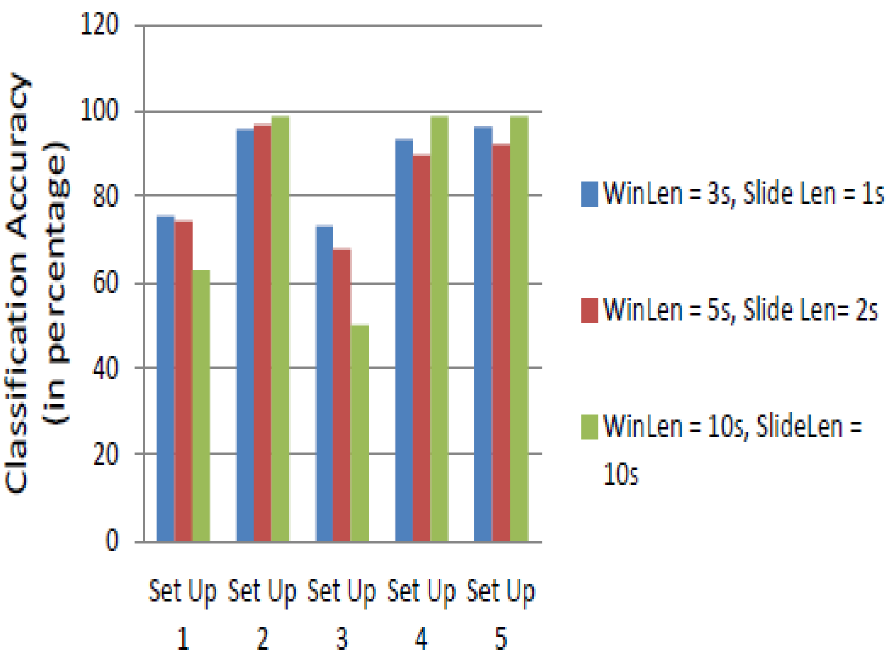
- Input signal data of one window length long is gathered.
- Feature set is computed from the window of data.
- The feature set is then submitted to the classifier which is trained using the training set data and pre-defined labels.

3. Classification Basics

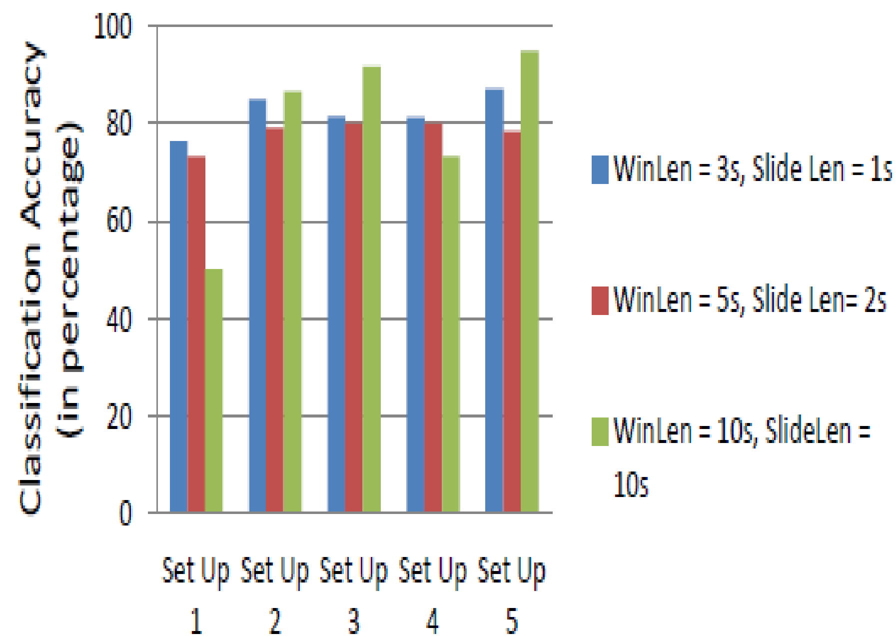
- Training of data
- Feature set formation
- Labels formation
- Testing of data

Classification Results - Discrete Time Classifier

Location Change



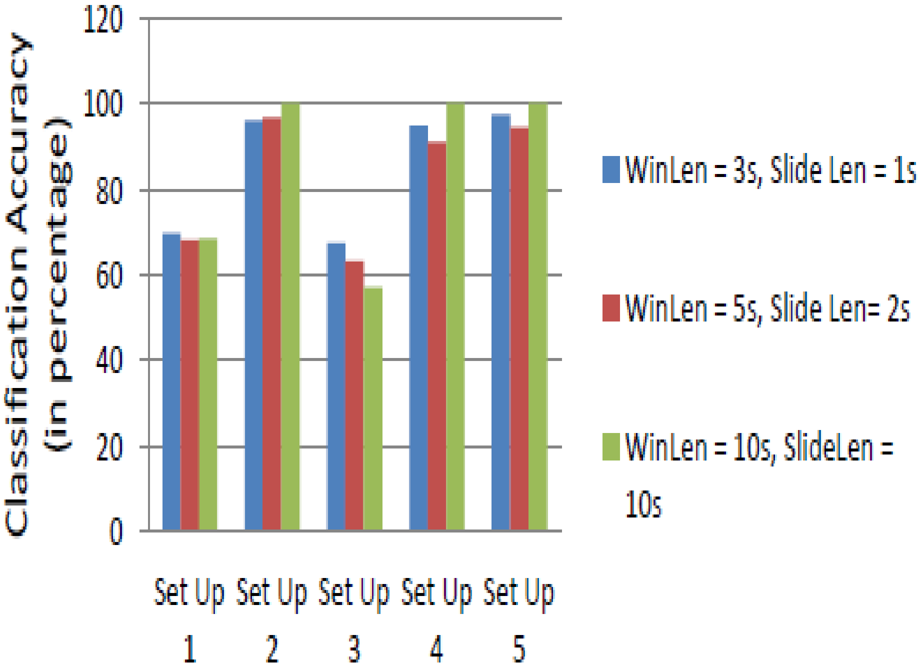
Mobility



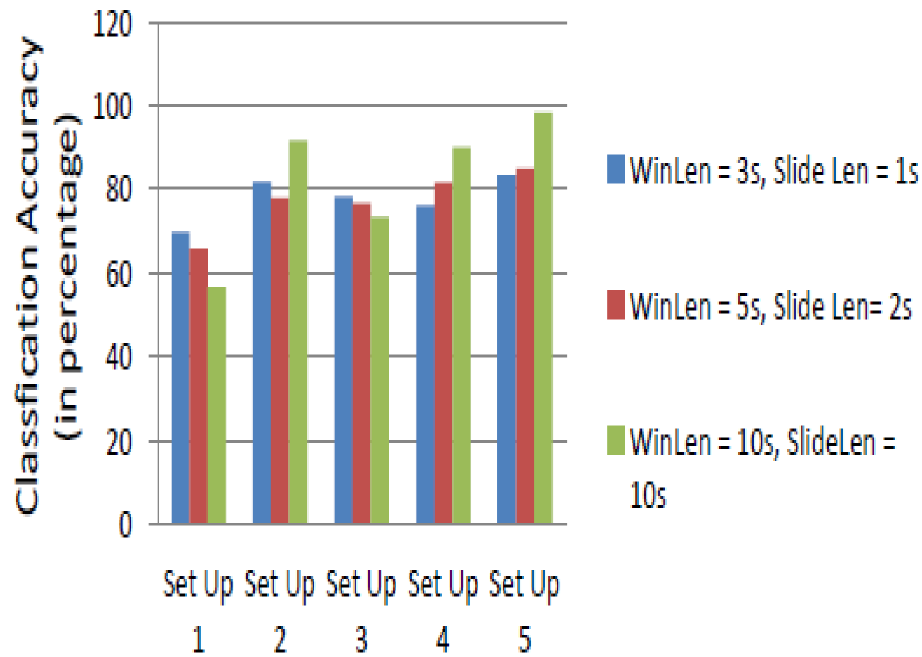
- The overall classification results were better with window length = 10s and slide length = 10s
- The separation of classes is more when the window length is 10s.
- Thus separation of signal patterns is directly related to its classification accuracy. Thus distribution distance is related to classification accuracy

Classification Results – Random Forest Classifier

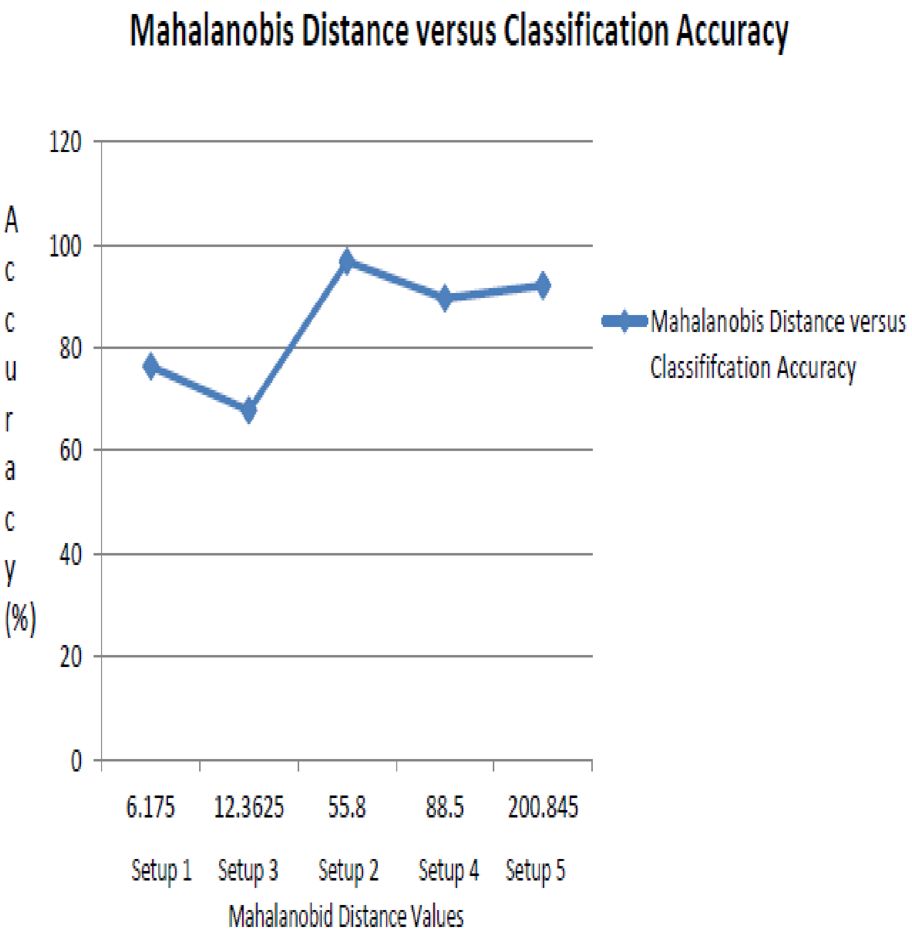
Location Change



Mobility



Research Summary



- The distribution distance has a logarithmic relationship with the classification accuracy.
- More the distribution distance, better the separation of RSSI patterns and better is the classification.
- The drop in accuracy for setup 3 implies that the symmetric nature of the setup results in lesser separation between the RSSI patterns.
- Classification values for setup 4 and setup 5 are lesser than that of setup 2 in spite of higher mahalanobis distances.
- Larger feature set results in higher complexity in classification which affects the performance.
- Optimization could be done in the classification approach to minimize this effect.

Conclusion

- Our work proposes a technique to evaluate an RFID system for state classification applications in a dynamic work environment.
- The deployment of RFID system can follow systematic steps using our work for efficient performance.
- Tag placement rules can be followed to minimize the affects of external factors on tag performance.
- Our work also gives insights into the features that could be used for classification.
- Different setups and their performance have been studied under different environmental conditions.
- Provides a groundwork for efficient deployment of the RFID setup in a trauma bay.

Future Work

- The RFID system has been deployed at the Children's National Medical Center (Washington) as part of this research and data has been collected during trauma simulations.
- The CNMC data can be studied with respect to read rates, distribution distance and classification scores.
- Other distribution distances like Earth Mover's Distance, Euclidean distance can be calculated and the results can be compared.
- The feature set used for classification can be enhanced for better classification accuracy.
- The application of RFID technology in a trauma bay looks promising and there is a lot of potential for research in this area.

Thanks

Questions ?